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TRACE ELEMENTS AND ORGANOCHLORINES IN SEDIMENTS AND FISH FROM MISSOURI RIVER RESERVOIRS IN MONTANA

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INTRODUCTION

The Federal Energy Regulatory Commission (FERC) is currently reviewing the application submitted by the Montana Power Company (MPC) for relicensing their hydroelectric dams on the Missouri and Madison Rivers in Montana. As part of the application process, MPC has proposed to monitor water quality in the Missouri-Madison River system. The monitoring plan was prepared by an inter-agency technical committee. The plan is designed to monitor the water quality and associated biological health at hydro-electric projects on the Madison-Missouri River system. This report addresses the component of the monitoring plan designed to establish baseline biocontaminant data by measuring trace elements and organochlorine compounds in sediments, algae, aquatic macroinvertebrates, and fish in the reservoirs and river segments of the system. MPC and the Montana Department of Fish, Wildlife and Parks (MDFWP) collected sediment, aquatic invertebrate, and fish samples from sites associated with the MPC reservoirs on the Missouri and Madison Rivers in 1994 and 1995 and analyzed them for trace elements and organochlorine compounds. As part of the cooperative nature of the interagency technical committee, MPC requested that the U.S. Fish and Wildlife Service's (USFWS) Montana Ecological Services Office assist in the interpretation of those analytical results. In this report, we present and interpret the MPC data and compare them with results of other studies conducted in the Missouri River drainage and elsewhere in Montana.

METHODS

In 1994, MPC and MDFWP personnel collected 2 sediment samples from each of 9 sites and 6 fish samples from each of 4 sites (Figure 1). The 2 sediment samples from each reservoir were collected above the impoundment, 1 sample 100-200 m upstream and 1 sample 0.5-1.5 km upstream. Three individuals of a predatory species and 3 individuals of a bottom-feeding species were collected at each fish sampling site. In 1995, 1 miscellaneous invertebrate sample (classes: Annelida and Crustacea) and 1 crayfish sample (class: Crustacea; family: Astacidae) were collected from each of 2 sites (Rainbow and Morony Reservoirs). Hebgen, Ennis, Hauser, Holter and Black Eagle Reservoirs were also sampled, but we obtained insufficient invertebrate biomass for analysis. Six fish samples were collected from each of the same 4 sites sampled for fish in 1994. The collectors endeavored to obtain 3 individuals of a predatory fish species and 3 individuals of a bottom-feeding species from each site in 1995, but they were not always successful in doing so.

Sediments were collected with a stainless steel Ekman dredge and stored in glass containers with aluminum foil placed between the contents and the lids. Invertebrates were collected in round tumble baskets filled with 20 cm x 20 cm squares of synthetic fiber (3M® hi-pro coiled-base web without abrasive) artificial substrate (Ingersoll et al., 1993) submerged behind each dam for 6 weeks during July and August. Fish were captured with electrofishing gear, weighed, measured, wrapped in aluminum foil, and then placed in double plastic bags. All samples were frozen as soon as practicable and remained frozen until chemical analyses were performed. Samples collected in 1994 were analyzed by Huntingdon Engineering & Environmental, Inc. Laboratory of (HEEI), St. Paul, MN, and samples collected in 1995 were analyzed by the Geochemical and Environmental Research Group (GERG), Texas A&M University, College Station, TX.

Samples were analyzed for the following trace elements: aluminum, arsenic, barium, beryllium, boron, cadmium, chromium, copper, iron, lead, magnesium, manganese, mercury, molybdenum, nickel, selenium, strontium, vanadium, and zinc. Organochlorine analytes in 1 or both years included: aldrin, alpha-BHC, beta-BHC, delta-BHC, gamma-BHC, alpha-chlordane, gamma-chlordane, oxychlordane, technical chlordane, o,p'-DDD, o,p'-DDE, o,p'-DDT, p,p'-DDD, p,p'-DDE, p,p'-DDT, dieldrin, alpha-endosulfan, beta-endosulfan, endosulfan II, endosulfan sulfate, endrin, endrin aldehyde, heptachlor, heptachlor epoxide, p,p'-methoxychlor, mirex, trans-nonachlor, cis-nonachlor, PCBs, and toxaphene.

In 1994, analyses were performed by HEEI in compliance with U.S. Environmental Protection Agency (USEPA) guidelines (USEPA 1986). Quality control samples included method/reagent blanks, laboratory control samples, matrix spikes, matrix spike duplicates, sample duplicates, and surrogate spikes. Analytical runs were validated by comparing the sample calibration curve against an external standard or a continuing calibration curve. Quality control samples were routinely examined to evaluate the data for acceptability. Data were peer reviewed and approved by the Laboratory Project Manager.

In 1995, samples were analyzed by GERG for arsenic and selenium using the hydride generation atomic absorption spectrophotometry (AAS) technique, mercury by cold vapor AAS, and the other trace elements by inductively coupled argon plasma emission spectroscopy. The organochlorine analyses were conducted using a gas chromatograph equipped with a dual capillary column/dual electron capture detector. GERG was under contract to the USFWS's Patuxent Analytical Control Facility, Laurel, MD, which approved its laboratory quality control and quality assurance procedures. The precision and accuracy of the laboratory analyses were confirmed with procedural blanks, duplicate analyses, test recoveries of spiked material and reference material analyses. All USFWS contaminant analyses receive a quality assurance review which includes round-robin tests among NBS and contract analytical laboratories.

Comparison of analytical results from 1994 and 1995 is difficult because the 2 laboratories that analyzed our samples reported very different lower detection limits. Samples analyzed for organochlorines by GERG in 1995 had practical quantitation limits that were at least an order of magnitude lower than samples analyzed by HEEI in 1994. Detection limits for trace elements differed by approximately a factor of 2. In the sections that follow, we present all trace element data regardless of detectability. However, we present data only for those organochlorine compounds that were detectable in the 1994 samples or that were detected in at least 1 of the 1995 samples at a concentration of 5.0 μg/kg wet weight (the detection limit reported by Martin and Hartman, 1985) or higher.

RESULTS AND DISCUSSION

TRACE ELEMENTS

Sediment. Sediment samples collected from the 4 upstream sites (Hebgen, Ennis [behind Madison Dam], Hauser, and Holter Reservoirs; Table 1) showed generally greater concentrations of all trace elements except barium and zinc than did samples from the 5 downstream sites (Black Eagle, Rainbow, Cochrane, Ryan, and Morony Reservoirs; Table 2). At Hebgen Reservoir, arsenic, beryllium, lead, and nickel concentrations exceeded the western U.S. geometric means (Shacklette and Boerngen 1984) or the maximum concentrations observed at National Wildlife Refuges and Waterfowl Production Areas in Montana (Palawski et al. 1991) or both. At Ennis Reservoir, lead and nickel concentrations exceeded the western U.S. means. At Hauser Reservoir, arsenic, lead, manganese, mercury, and nickel concentrations exceeded one or both regional standards. At Holter Reservoir, lead, mercury, nickel, and zinc concentrations exceeded the western U.S. mean concentrations.

Among the downstream sites, only Morony Reservoir showed elevated concentrations of any element other than zinc. At Morony, nickel concentrations exceeded the western U.S. mean. Zinc concentrations from samples collected at Rainbow, Cochrane, Ryan, and Morony Reservoirs exceeded the western U.S. mean concentration.

Trace element concentrations in sediment samples from the upstream reservoirs may have been higher than downstream concentrations due to the mineral-rich nature of the upper Missouri and Madison River drainages. Or, elevated trace element concentrations may represent the effects of past mineral extraction and associated environmental contamination in the drainage.

Aquatic Invertebrates. Concentrations of aluminum, arsenic, barium, and chromium were clearly elevated in miscellaneous invertebrates collected from both Rainbow and Morony Reservoirs (Table 3). Arsenic concentrations were particularly high in both samples, over 50% higher than the highest concentration among a large sample (n = 357) of invertebrates collected elsewhere in Montana (Palawski et al. 1991). Arsenic concentrations did not exceed the 30 μg/g (presumably wet weight) concentration in ration reported by Eisler (1994) to adversely affect growth in ducklings. Chromium concentrations in both samples exceeded the 0.2 μg/g dry weight concentration proposed by Eisler (1986) for the protection of fish and fish predators. We do not know what effects, if any, the high aluminum and barium concentrations might have on the organisms themselves or their predators.

We have few comparative data for trace element concentrations in crayfish. DeWeese et al. (1993) analyzed 4 crayfish composites from Colorado, Thodal and Tuttle (1996) analyzed 1 crayfish composite from California and 1 from Nevada, and Olson (1994) analyzed 3 individual crayfish from North Dakota for trace elements. Phillips (1985) analyzed crayfish from the Clark Fork River in western Montana for copper, and Welsh and Maughan (1994) analyzed crayfish from Arizona and California for selenium. For all elements except arsenic, barium, and chromium, concentrations in the crayfish samples collected at Rainbow and Morony Reservoirs (Table 3) were either similar to or lower than the concentrations reported from elsewhere in the United States. The sites sampled by DeWeese et al. (1993), Olson (1994), Phillips (1985), and Welsh and Maughan (1994) were known or suspected to be polluted by historical mining activities or irrigation drainage. Even so, only DeWeese et al. (1993) felt that aquatic life might have been threatened by trace element concentrations in crayfish on their study area. They felt that, although detection limits were too high to quantify chromium concentrations, the 0.2 µg/g dry weight concentration proposed by Eisler (1986) to protect fish or fish predators might have been exceeded. That concentration was exceeded in both of our crayfish samples. Although arsenic and barium seemed elevated, we do not know what effects the observed concentrations of trace elements other than chromium might have on crayfish or their predators at Rainbow and Morony Reservoirs.

Fish. Predatory fish collected included mountain whitefish (Prosopium williamsoni), brown trout (Salmo trutta), and rainbow trout (Onchorhynchus mykiss). Bottom feeding fish sampled were longnose suckers (Catostomus catostomus) and white suckers (Catostomus commersoni; Tables 4 through 7). Among brown and rainbow trout collected in both years, concentrations of all elements seemed generally higher at the upstream sites and lower downstream. We saw no such trend in mountain whitefish or longnose suckers. White suckers were sampled from only 1 site.

Compared to trace element concentrations in fish of the same or similar taxa collected from National Wildlife Refuges and Waterfowl Production Areas in Montana (Palawski et al. 1991), arsenic, selenium, and strontium in fish collected during this study seemed elevated. Many of the fish collected by Palawski et al. (1991) came from west of the continental divide, where trace element concentrations in general and strontium concentrations in particular are lower in sediments and biota than they are east of the divide. Arsenic, copper, and selenium in some rainbow and brown trout and in longnose suckers and mountain whitefish exceeded the geometric mean concentrations of those elements reported by Lowe et al. (1985) in a nationwide survey of freshwater fish. The higher trace element concentrations observed in brown and rainbow trout collected from upstream sites may simply reflect the higher background concentrations observed in sediments collected from the upper Missouri and Madison Rivers.

We do not know what effects the observed arsenic concentrations might have on fish or their predators in the upstream reservoirs. The observed concentrations do not exceed the published concern levels (Eisler 1994).

As was the case for invertebrate samples, chromium concentrations in some fish samples exceeded the 0.2 µg/g dry weight concentration proposed by Eisler (1986) for protection of fish and fish predators. Exceedences occurred at Hot Springs, Holter, Great Falls, and Morony. We do not know what implications those chromium concentrations may have for reservoir management. USFWS contract analytical laboratories have only recently become capable of detecting chromium at or below the proposed concern level, so our pre-1995 data from elsewhere in Montana do not provide an adequate basis for comparison.

ORGANOCHLORINES

Sediment. Sediment samples from the Missouri and Madison River reservoirs were virtually devoid of detectable organochlorine residues (Tables 8 and 9). Only at Hauser Reservoir were any residues detected. Those compounds were p,p'-DDT, endosulfan sulfate, endrin aldehyde, and PCBs.

We have few comparative data for organochlorine residues in sediments from Montana. Knapton et al. (1988) found no detectable residues of the six pesticides for which samples collected in the Sun River area were analyzed. Palawski et al. (1990) reported no detectable organochlorine residues in 22 sediment samples collected from eastern Montana, and DuBois et al. (1992) detected no organochlorine residues in four sediment samples from Bowdoin National Wildlife Refuge. Phillips and Bahls (1994) found no detectable PCBs in the sediments of Hebgen, Hauser, or Holter Reservoirs. The scarcity of detectable residues in sediments collected during this study probably reflects the limited historical use of organochlorine pesticides in the upper Missouri drainage.

Aquatic Invertebrates. The only organochlorine residues detected in aquatic invertebrates at a concentration of 5.0 μg/kg wet weight or higher were PCBs(Table 10). PCB concentrations in the 2 miscellaneous invertebrate samples (12.0 μg/kg wet weight, Morony; 21.9 μg/kg wet weight, Rainbow) and in the 2 crayfish samples (11.2 μg/kg wet weight, Morony; 12.5 μg/kg wet weight, Rainbow) were generally lower than concentrations in fish.

Fish. In 1994, 7 organochlorine compounds were detected in fish (Table 11). Those were beta-BHC, p,p'-DDD, p,p'-DDE, p,p'-DDT, dieldrin, endrin, and heptachlor. Residues of at least one compound were detected in all species except white suckers. The most frequently occurring compound among those detected was p,p'-DDE. The other compounds were detected most frequently in rainbow trout and longnose suckers. We could discern no geographical pattern in organochlorine residue occurrence.

In 1995, 6 organochlorine compounds were detected at concentrations greater than 5.0 μg/kg wet weight in fish samples (Table 12). Those compounds were alpha-BHC, p,p'-DDD, p,p'-DDE, p,p'-DDT, dieldrin, and total PCBs. Residues of p,p'-DDD, p,p'-DDE, p,p'-DDT, and PCBs were present in all species from all sites. Longnose sucker samples were found to contain residues of more compounds than were other species of fish, although not necessarily the highest concentrations of those compounds. Again, we found no pattern of organochlorine occurrence among the sites sampled.

DDE was the most commonly detected organochlorine compound in fish collected elsewhere in Montana and the north-central United States (Martin and Hartman 1985, Schmitt et al. 1985, Schmitt et al. 1990), as it was in this study. Concentrations of organochlorine compounds detected in this study were similar to the concentrations reported by Martin and Hartman (1985) and considered by them to be relatively low. Schmitt et al. (1985, 1990) reported organochlorine concentrations from brown trout and white suckers collected from the Missouri River at Great Falls that were very similar to the concentrations reported for those species in this study. Phillips and Bahls (1994) reported no detectable PCBs in fish from Hebgen and Hauser Reservoirs but did find low PCB concentrations in walleyes (Stizostedion vitreum) from Holter Reservoir.

CONCLUSIONS

With the exceptions of some trace elements in sediment from upstream reservoirs, trace element and organochlorine concentrations in sediment and fish collected from reservoirs on the Missouri and Madison Rivers were typical of concentrations reported from elsewhere in the Missouri River drainage and the western United States. Arsenic concentrations in miscellaneous invertebrates from Rainbow and Morony Reservoirs were the highest ever recorded from Montana. However, those concentrations did not exceed published concern levels. Chromium concentrations in miscellaneous aquatic invertebrates and crayfish collected from Rainbow and Morony Reservoirs, and in some fish samples from Hot Springs, Holter, Great Falls, and Morony, exceeded the concentration proposed for protection of fish and fish predators.

In view of the elevated arsenic concentrations in aquatic invertebrates from reservoirs with relatively low arsenic concentrations in sediment, we recommend that invertebrate and fish samples be collected from Hebgen and Hauser Reservoirs, where arsenic concentrations in sediment were high, and that they be analyzed for trace elements.

We feel that the concentrations reported in this study represent baseline contaminant levels associated with the Madison-Missouri River Hydro-Projects. These data can be compared with future contaminant biomonitoring data to determine whether project operations during the FERC license period are affecting the level of exposure or bioaccumulation of contaminants.

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Figure 2. MAP OF MISSOURI - MADISON RIVER SYSTEM SHOWING MPC PROJECTS AND BIOCONTAMINANT FISH SAMPLING LOCATIONS

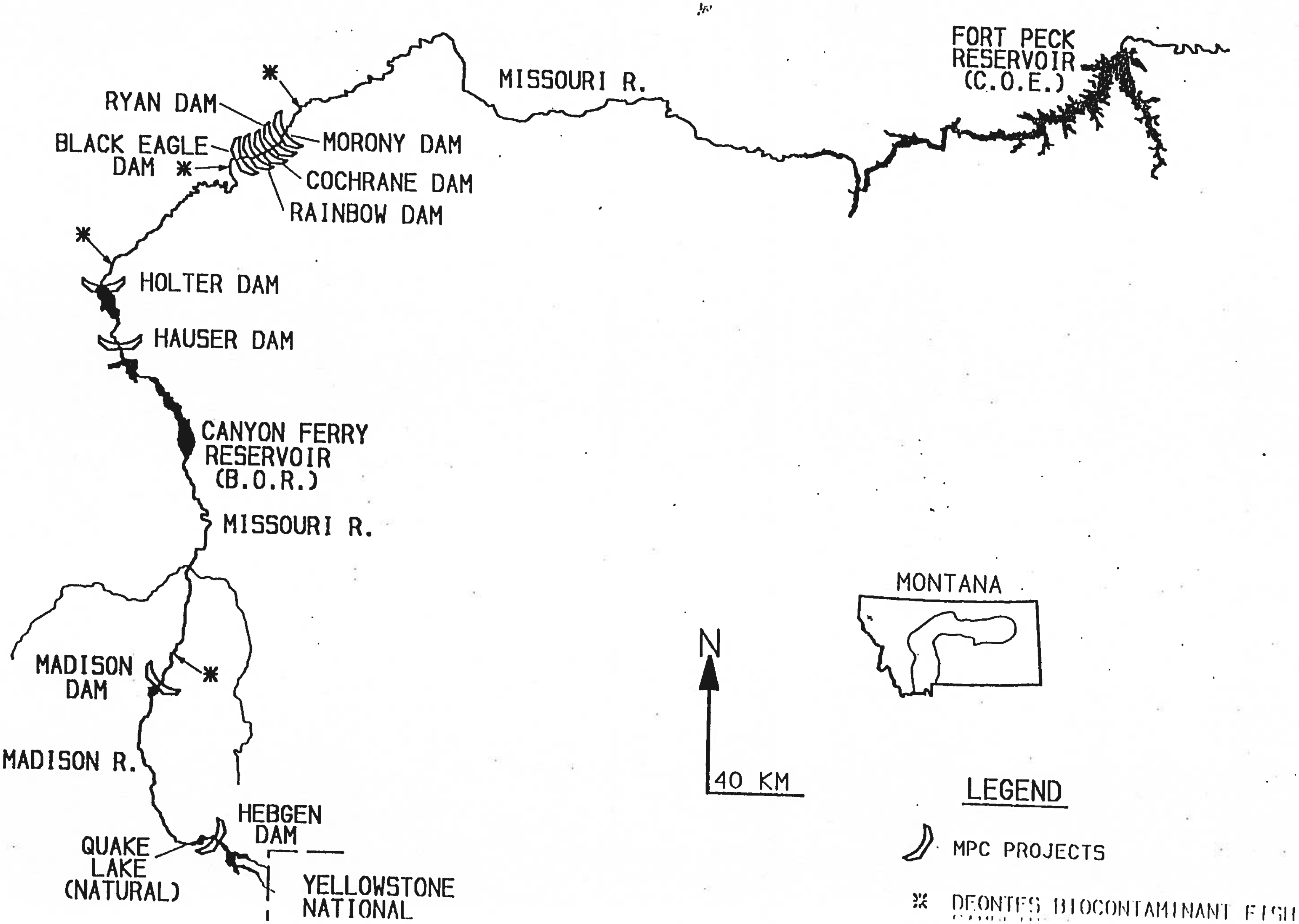

Table 1. Trace element concentrations (µg/g dry weight) in sediments collected from Hebgen, Ennis, Hauser, and Holter Reservoirs during 1994. Data are presented as geometric means with ranges in parentheses.

Element	Hebgen (n = 2)	Ennis (n = 2)	Hauser (n = 2)	Holter (n = 2)
Aluminum	9,644 (6,200-15,000)	6,397 (4,400-9,300)	14,997 (14,000-16,000)	13,000 (13,000-13,000)
Arsenic	124.92 (94.00-166.00)	11.96 (11.00-13.00)	36.06 (25.00-52.00)	25.10 (21.00-30.00)
Barium	85.32 (56.00-130.00)	78.99 (52.00-120.00)	193.39 (170.00-220.00)	180.00 (180.00-180.00)
Beryllium	3.64 (2.50-5.30)	0.89 (0.79-1.00)	0.57 (0.22-1.50)	1.15 (1.10-1.20)
Boron	21.49 (21.00-22.00)	10.32 (7.10-15.00)	NC (<5.00-<5.00)	NC (<5.00-<5.00)
Cadmium	NC[A] (<0.50-<0.50)	NC (<0.50-<0.50)	NC (<0.50-<0.50)	NC (<5.00-<5.00)
Chromium	13.58 (9.70-19.00)	27.50 (14.00-54.00)	31.30 (28.00-35.00)	17.97 (17.00-19.00)
Copper	12.59 (9.90-16.00)	12.80 (9.10-18.00)	36.08 (31.00-42.00)	24.98 (24.00-26.00)
Iron	13,282 (9,800-18,000)	14,491 (10,000-21,000)	19,900 (18,000-22,000)	18,493 (18,000-19,000)
Lead	31.08 (14.00-69.00)	18.22 (7.90-42.00)	39.60 (28.00-56.00)	32.31 (29.00-36.00)
Magnesium	NA[B]	NA	9,900 (9,900-9,900)	11,000 (11,000-11,000)
Manganese	818.5 (670.0-1,000.0)	377.9 (340.0-420.0)	1,517 (1,000-2,300)	1,022 (870.0-1,200.0)
Mercury	NC (<0.20-<0.20)	NC (<0.20-<0.20)	0.17 (0.13-0.21)	0.145 (0.14-0.15)
Molybdenum	4.42 (<5.00-7.80)	NC (<5.00-<5.00)	NC (<0.50-<0.50)	NC (<0.50-<0.50)
Nickel	11.424 (8.70-15.00)	21.63 (13.00-36.00)	19.18 (16.00-23.00)	16.49 (16.00-17.00)
Selenium	NC (<0.15-<0.15)	NC (<0.15-<0.15)	0.18 (<0.15-0.420)	NC (<0.15-<0.15)
Strontium	NC (<5.00-<5.00)	NC (<5.00-<5.00)	77.33 (65.00-92.00)	71.36 (67.00-76.00)
Vanadium	18.44 (17.00-20.00)	14.78 (9.50-23.00)	19.77 (17.00-23.00)	20.00 (20.00-20.00)
Zinc	38.73 (30.0-50.0)	20.2 (14.0-29.0)	118.3 (100.0-140.0)	91.4 (88.0-95.0)

[A] NC = Not calculable, element was below the practical quantitation limit.
[B] NA = Not analyzed.

Table 2. Trace element concentrations (µg/g dry weight) in sediments collected from Black Eagle, Rainbow, Cochrane, Ryan, and Morony Reservoirs during 1994. Data are presented as geometric means with ranges in parentheses.

Element	Black Eagle (n = 2)	Rainbow (n = 2)	Cochrane (n = 2)	Ryan (n = 2)	Morony (n = 2)
Aluminum	7,057 (6,000-8,300)	10,387 (8,300-13,000)	9,950 (9,000-11,000)	10,330 (9,700-11,000)	14,283 (12,000-17,000)
Arsenic	7.17 (6.50-7.90)	10.11 (9.30-11.00)	11.49 (11.00-12.00)	14.00 (14.00-14.00)	14.42 (13.00-16.00)
Barium	118.74 (94.00-150.00)	174.93 (170.00-180.00)	174.36 (160.00-190.00)	200.00 (200.00-200.00)	220.00 (220.00-220.00)
Beryllium	0.58 (0.46-0.63)	0.74 (0.60-0.92)	0.76 (0.69-0.84)	0.83 (0.82-0.83)	1.08 (0.98-1.20)
Boron	NC[a] (<5.00-<5.00)	NC (<5.00-<5.00)	NC (<5.00-<5.00)	NC (<5.00-<5.00)	NC (<5.00-<5.00)
Cadmium	NC (<0.50-<0.50)	NC (<0.50-<0.50)	NC (<0.50-<0.50)	0.65 (<0.50-<0.50)	NC (<0.50-<0.50)
Chromium	8.78 (7.00-11.00)	12.85 (11.00-15.00)	12.41 (11.00-14.00)	12.49 (12.00-13.00)	16.43 (15.00-18.00)
Copper	7.09 (5.40-9.30)	15.10 (12.00-19.00)	21.98 (21.00-23.00)	28.14 (22.00-36.00)	29.85 (27.00-33.00)
Iron	12,410 (11,000-14,000)	16,432 (15,000-18,000)	14,967 (14,000-16,000)	15,492 (15,000-16,000)	19,900 (18,000-22,000)
Lead	9.17 (8.40-10.00)	12.96 (12.00-14.00)	14.70 (12.00-18.00)	12.85 (11.00-15.00)	18.330 (16.00-21.00)
Magnesium	6,000 (4,500-8,000)	9,263 (7,800-11,000)	9,670 (8,500-11,000)	10,488 (10,000-11,000)	12,490 (12,000-13,000)
Manganese	214.48 (200.0-230.0)	267.02 (230.0-310.0)	263.82 (240.0-290.0)	294.96 (290.0-300.0)	414.25 (390.0-440.0)
Mercury	NC (<0.20-<0.20)	NC (<0.20-<0.20)	NC (<0.20-<0.20)	NC (<0.20-<0.20)	NC (<0.20-<0.20)
Molybdenum	NC (<1.00-<1.00)	NC (<1.00-<1.00)	NC (<1.00-<1.00)	NC (<1.00-<1.00)	NC (<1.00-<1.00)
Nickel	8.24 (7.00-9.70)	11.96 (11.00-13.00)	12.41 (11.00-14.00)	13.49 (13.00-14.00)	15.43 (14.00-17.00)
Selenium	NC (<0.15-<0.15)	NC (<0.15-<0.15)	NC (<0.15-<0.15)	NC (<0.15-<0.15)	NC (<0.15-<0.15)
Strontium	64.71 (53.0-79.0)	96.70 (85.00-110.00)	83.16 (76.00-91.00)	85.49 (84.00-87.00)	108.44 (98.00-120.00)
Vanadium	14.28 (12.00-17.00)	17.32 (15.00-20.00)	17.89 (16.00-20.00)	20.00 (20.00-20.00)	22.36 (20.00-25.00)
Zinc	33.47 (28.0-40.0)	58.46 (51.0-67.0)	69.41 (66.0-73.0)	112.87 (91.0-140.0)	97.47 (95.0-100.0)

[a] NC = Not calculable, element was below the practical quantitation limit.

Table 3. Trace element concentrations (µg/g wet weight) in aquatic invertebrates collected from the Missouri River drainage in Montana during 1995. Data are presented as geometric means with ranges in parentheses.

	Miscellaneous invertebrates		Crayfish	
Element	Rainbow (n = 1)	Morony (n = 1)	Rainbow (n = 1)	Morony (n = 1)
Aluminum	110.89	279.04	181.31	147.93
Arsenic	6.001	6.174	0.858	0.987
Barium	13.050	8.570	27.510	35.125
Beryllium	<0.011	0.014	<0.021	<0.031
Boron	<0.226	0.322	0.600	<0.617
Cadmium	0.023	0.012	<0.021	<0.031
Chromium	0.704	0.383	0.922	0.786
Copper	2.140	3.766	11.121	18.732
Iron	140.49	213.79	132.02	104.57
Lead	0.180	0.201	0.193	<0.154
Magnesium	142.10	192.94	374.44	560.28
Manganese	4.757	22.401	11.488	22.959
Mercury	0.009	0.012	0.019	0.031
Molybdenum	<0.226	<0.237	<0.429	<0.617
Nickel	0.149	0.393	0.210	0.308
Selenium	0.530	0.438	0.300	0.308
Strontium	5.224	22.459	96.384	206.78
Vanadium	0.224	0.556	0.397	0.345
Zinc	23.51	16.22	14.72	16.09

Table 4. Trace element concentrations (µg/g wet weight) in mountain whitefish collected from the Missouri River drainage in Montana during 1994 and 1995. Data are presented as geometric means with ranges in parentheses.

Element	Hot Springs 1994 (n = 3)	Hot Springs 1995 (n = 3)	Great Falls 1995 (n = 3)
Aluminum	6.497 (5.30-7.50)	2.175 (<1.34-6.04)	9.297 (1.73-38.90)
Arsenic	NC[A] (<0.15-<0.15)	NC (<0.13-<0.15)	NC (<0.13-<0.15)
Barium	NC (<0.50-<0.50)	0.339 (<0.30-0.56)	0.647 (0.42-0.90)
Beryllium	NC (<0.05-<0.05)	NC (<0.03-<0.03)	NC (<0.02-<0.03)
Boron	NC (<5.00-<5.00)	NC (<0.54-0.71)	NC (<0.51-<0.59)
Cadmium	NC (<0.50-<0.50)	NC (<0.03-<0.03)	NC (<0.02-<0.03)
Chromium	NC (<0.50-<0.50)	NC (<0.13-0.38)	NC (<0.13-<0.15)
Copper	NC (<0.50-<0.50)	0.571 (0.46-0.75)	0.615 (0.49-0.76)
Iron	18.54 (15.0-25.0)	21.01 (16.4-29.9)	31.45 (6.5-219.1)
Lead	NC (<2.50-2.70)	NC (<0.13-<0.15)	NC (<0.13-0.14)
Magnesium	286.39 (270.0-300.0)	304.12 (277.6-326.8)	323.00 (303.7-343.3)
Manganese	1.724 (1.60-2.00)	3.030 (2.37-4.28)	2.527 (1.55-5.51)
Mercury	NC (<0.10-<0.10)	0.038 (0.02-0.06)	0.058 (0.05-0.06)
Molybdenum	NC (<1.00-<1.00)	NC (<0.54-0.70)	NC (<0.51-<0.59)
Nickel	NC (<1.00-<1.00)	NC (<0.13-<0.15)	NC (<0.13-0.22)
Selenium	0.878 (0.62-1.20)	1.208 (0.75-1.58)	1.054 (0.53-3.11)
Strontium	3.505 (2.50-4.20)	3.985 (3.29-5.44)	6.382 (4.35-8.93)
Vanadium	0.700 (0.55-0.89)	NC (<0.13-0.16)	0.187 (<0.15-0.32)
Zinc	15.58 (14.0-18.0)	19.06 (18.25-20.65)	19.39 (14.51-27.41)

[A] NC = Not calculable. More than half of the samples were below the practical quantitation limit.

Table 5. Trace element concentrations (µg/g wet weight) in brown trout collected from the Missouri River drainage in Montana during 1994 and 1995. Data are presented as geometric means with ranges in parentheses.

Element	Hot Springs 1994 (n = 1)	Hot Springs 1995 (n = 2)	Great Falls 1994 (n = 1)	Great Falls 1995 (n = 2)	Morony 1994 (n = 3)	Morony 1995 (n = 3)
Aluminum	8.700	1.433 (<1.27-3.23)	9.000	3.914 (3.49-4.39)	7.725 (5.9-9.3)	NC[a] (<1.22-2.86)
Arsenic	0.210	NC (<0.12-<0.13)	<0.150	NC (<0.13-<0.14)	NC (<0.15-<0.15)	NC (<0.12-<0.14)
Barium	<0.500	NC (<0.24-<0.25)	<0.500	NC (<0.27-<0.28)	NC (<0.50-<0.50)	NC (<0.24-<0.29)
Beryllium	<0.050	NC (<0.02-<0.02)	<0.050	NC (<0.03-<0.03)	NC (<0.05-<0.05)	NC (<0.02-<0.03)
Boron	<5.000	NC (<0.49-<0.51)	<5.000	NC (<0.54-<0.57)	NC (<5.00-<5.00)	NC (<0.49-<0.58)
Cadmium	<0.500	NC (<0.02-<0.02)	<0.500	NC (<0.03-<0.03)	NC (<5.00-<5.00)	NC (<0.02-<0.03)
Chromium	<0.500	0.106 (<0.13-0.18)	0.510	0.136 (<0.14-0.26)	NC (<0.50-<0.50)	0.128 (<0.14-0.20)
Copper	2.500	1.794 (0.95-3.39)	1.600	1.164 (1.12-1.21)	2.967 (1.70-6.40)	2.343 (1.62-3.57)
Iron	19.000	16.94 (16.74-17.15)	10.000	14.77 (14.04-15.52)	19.66 (16.0-25.0)	17.60 (14.31-19.97)
Lead	<2.500	NC (<0.12-<0.13)	<2.500	NC (<0.13-<0.14)	NC (<2.50-<2.50)	NC (<0.12-<0.14)
Magnesium	260.00	294.06 (270.1-320.2)	320.00	261.55 (249.9-273.7)	313.19 (300.0-320.0)	240.59 (230.0-261.9)
Manganese	17.000	1.122 (0.87-1.44)	1.600	0.647 (0.45-0.92)	0.920 (0.58-1.60)	NC (<0.24-1.01)
Mercury	<0.100	0.055 (0.05-0.06)	0.070	0.076 (0.06-0.09)	0.180 (0.15-0.23)	0.102 (0.04-0.20)
Molybdenum	<1.000	NC (<0.49-<0.51)	<1.000	0.434 (<0.57-0.66)	NC (<1.00-<1.00)	NC (<0.49-<0.58)
Nickel	<1.000	0.157 (0.15-0.17)	<1.000	NC (<0.13-<0.14)	NC (<1.00-<1.00)	0.127 (<0.12-0.22)
Selenium	0.380	0.470 (0.41-0.53)	0.520	0.576 (0.51-0.65)	0.606 (0.33-0.99)	0.669 (0.38-1.13)
Strontium	3.600	2.873 (2.00-4.12)	12.000	3.993 (3.05-5.23)	10.134 (8.60-11.00)	3.187 (2.01-6.09)
Vanadium	<0.500	0.088 (<0.13-0.12)	0.770	0.170 (0.14-0.20)	0.518 (<0.50-0.83)	NC (<0.12-<0.14)
Zinc	26.000	22.60 (20.5-24.9)	19.000	34.41 (26.7-44.3)	37.33 (29.0-46.0)	21.88 (18.91-23.95)

[a] NC = Not calculable. More than half of the samples were below the practical quantitation limit.

Table 6. Trace element concentrations (µg/g wet weight) in rainbow trout collected from the Missouri River drainage in Montana during 1994 and 1995. Data are presented as geometric means with ranges in parentheses.

Element	Hot Springs 1994 (n = 2)	Hot Springs 1995 (n = 1)	Holter 1994 (n = 3)	Holter 1995 (n = 3)	Great Falls 1994 (n = 2)	Great Falls 1995 (n = 1)
Aluminum	15.799 (7.8-32.0)	139.856	8.752 (6.3-14.0)	20.933 (7.2-52.2)	NC (<5.0-<5.0)	15.400
Arsenic	0.170 (0.17-0.17)	<0.122	NC (<0.15-<0.15)	NC (<0.13-<0.14)	NC (<0.15-<0.15)	<0.137
Barium	1.382 (0.91-2.10)	5.878	0.448 (<0.50-0.72)	0.863 (<0.27-2.97)	NC (<0.50-<0.50)	0.330
Beryllium	NC[a] (<0.05-<0.05)	<0.024	NC (<0.05-<0.05)	NC (<0.03-<0.03)	NC (<0.05-<0.05)	<0.027
Boron	NC (<5.0-<5.0)	<0.486	NC (<5.0-<5.0)	NC (<0.51-0.58)	NC (<0.5-<0.5)	<0.549
Cadmium	NC (<0.50-<0.50)	<0.024	NC (<0.50-<0.50)	NC (<0.03-<0.03)	NC (<0.50-<0.50)	<0.027
Chromium	0.400 (<0.50-0.64)	0.668	NC (<0.50-<0.50)	NC (<0.13-0.44)	NC (<0.50-<0.50)	<0.137
Copper	0.578 (0.53-0.63)	1.106	1.446 (0.96-2.10)	1.081 (0.95-1.24)	1.308 (0.57-3.00)	1.008
Iron	29.66 (20.0-44.0)	244.54	23.88 (16.0-37.0)	36.88 (19.9-69.7)	11.03 (6.4-19.0)	24.62
Lead	1.803 (<2.50-2.60)	0.340	NC (<2.50-<2.50)	NC (<0.13-<0.14)	NC (<2.50-<2.50)	<0.137
Magnesium	366.61 (320.0-420.0)	377.64	265.32 (230.0-290.0)	320.57 (249.4-405.5)	269.26 (250.0-290.0)	286.13
Manganese	5.083 (3.80-6.80)	31.352	4.255 (2.50-7.90)	9.796 (1.92-31.81)	NC (<0.50-<0.50)	1.714
Mercury	NC (<0.10-<0.20)	0.053	NC (<0.04-<0.04)	0.081 (0.04-0.14)	0.238 (0.21-0.27)	0.170
Molybdenum	NC (<1.00-<1.00)	<0.486	NC (<1.00-<1.00)	NC (<0.51-0.77)	NC (<1.00-<1.00)	<0.549
Nickel	NC (<1.00-<1.00)	0.544	NC (<1.00-<1.00)	NC (<0.13-0.19)	NC (<1.00-<1.00)	0.151
Selenium	0.330 (0.32-0.34)	0.219	0.279 (0.21-0.49)	0.290 (0.24-0.32)	0.410 (0.30-0.56)	0.549
Strontium	6.782 (4.60-10.00)	5.696	4.468 (2.80-6.50)	4.979 (1.60-11.70)	1.117 (0.96-1.30)	1.502
Vanadium	0.917 (0.70-1.20)	0.688	NC (<0.50-<0.50)	NC (<0.13-0.20)	NC (<0.50-<0.50)	0.211
Zinc	29.46 (28.0-31.0)	23.12	13.22 (11.0-15.0)	22.27 (20.53-23.31)	7.42 (5.0-11.0)	19.02

[a] NC = Not calculable. More than half of the samples were below the practical quantitation limit.

Table 7. Trace element concentrations (µg/g wet weight) in suckers collected from the Missouri River drainage in Montana during 1994 and 1995. Data are presented as geometric means with ranges in parentheses.

	Longnose sucker				White sucker	
Element	Holter 1994 (n = 3)	Holter 1995 (n = 3)	Great Falls 1994 (n = 1)	Morony 1994 (n = 3)	Morony 1995 (n = 3)	Great Falls 1994 (n = 2)
Aluminum	22.19 (13.0-30.0)	34.21 (13.9-85.3)	42.00	29.00 (20.0-61.0)	64.76 (49.8-83.2)	33.27 (27.0-41.0)
Arsenic	0.243 (0.23-0.26)	NC (<0.12-<0.16)	0.280	0.153 (<0.15-0.24)	0.157 (<0.16-0.25)	NC (<0.15-<0.15)
Barium	1.247 (0.98-1.80)	1.093 (0.89-1.30)	3.600	0.965 (<0.50-2.00)	1.392 (0.83-1.86)	2.214 (1.40-3.50)
Beryllium	NC[a] (<0.05-<0.05)	NC (<0.02-<0.03)	<0.050	NC (<0.05-<0.05)	NC (<0.03-<0.03)	NC (<0.05-<0.05)
Boron	NC (<5.00-<5.00)	NC (<0.50-1.37)	<5.000	NC (<5.00-<5.00)	NC (<0.56-<0.70)	NC (<5.00-<5.00)
Cadmium	NC (<0.50-<0.50)	NC (<0.02-<0.03)	<0.500	NC (<0.50-<0.50)	0.025 (<0.04-0.03)	NC (<0.50-<0.50)
Chromium	0.452 (<0.50-0.67)	NC (<0.12-<0.16)	0.780	NC (<0.50-0.55)	0.133 (<0.18-0.16)	NC (<0.50-<0.50)
Copper	0.997 (0.90-1.10)	0.838 (0.77-0.90)	0.820	0.715 (0.50-0.86)	0.806 (0.75-0.89)	0.880 (0.86-0.90)
Iron	34.08 (18.0-55.0)	43.62 (27.3-61.2)	6.60	47.79 (31.0-110.0)	55.83 (45.0-71.2)	57.36 (47.0-70.0)
Lead	NC (<2.50-<2.50)	NC (<0.12-<0.16)	<2.500	NC (<2.50-<2.50)	NC (<0.14-<0.18)	NC (<2.50-<2.50)
Magnesium	302.44 (260.0-380.0)	264.26 (210.4-315.3)	470.00	305.79 (290.0-340.0)	280.25 (230.9-346.3)	355.00 (350.0-360.0)
Manganese	13.904 (12.00-16.00)	12.541 (9.54-19.94)	13.000	6.817 (6.00-8.00)	5.498 (4.34-6.90)	5.020 (3.60-7.00)
Mercury	0.097 (0.05-0.18)	0.110 (0.08-0.14)	<0.040	NC (<0.20-0.13)	0.075 (0.06-0.09)	NC (<0.04-<0.04)
Molybdenum	NC (<1.00-<1.00)	NC (<0.50-<0.66)	<1.000	NC (<1.00-<1.00)	NC (<0.56-<0.70)	NC (<1.00-<1.00)
Nickel	NC (<1.00-<1.00)	NC (<0.12-0.16)	<1.000	NC (<1.00-<1.00)	0.201 (<0.18-0.34)	NC (<1.00-<1.00)
Selenium	0.230 (0.17-0.31)	0.278 (0.26-0.30)	0.480	0.312 (0.28-0.35)	0.274 (0.25-0.29)	0.372 (0.33-0.42)
Strontium	10.075 (6.80-16.00)	5.708 (3.19-10.22)	28.000	14.736 (10.00-20.00)	7.916 (3.67-18.53)	18.000 (18.00-18.00)
Vanadium	0.577 (<0.50-1.10)	0.142 (<0.16-0.20)	1.500	0.875 (0.67-1.10)	NC (<0.14-<0.18)	0.923 (0.87-0.98)
Zinc	12.56 (11.0-15.0)	13.13 (10.0-16.4)	17.00	17.10 (14.0-21.0)	15.92 (14.65-16.97)	11.00 (11.00-11.00)

[a] NC = Not calculable. More than half of the samples were below the practical quantitation limit.

Table 8. Organochlorine residues (μg/kg wet weight) in sediments collected from Missouri River reservoirs in Montana during 1994. Data are presented as geometric means with ranges in parentheses.

Compound	Hebgen (n = 2)	Ennis (n = 2)	Hauser (n = 2)	Holter (n = 2)
p,p'-DDT	NC[A] (<20-<24)	NC (<2.3-<4.1)	19.42 (8.2-46)	NC (<4.3-<5.9)
Endosulfan Sulfate	NC (<20-<24)	NC (<2.3-<4.1)	4.43 (<9.8-4.0)	NC (<4.3-<5.9)
Endrin Aldehyde	NC (<20-<24)	NC (<2.3-<4.1)	5.22 (<3.9-14)	NC (<4.3-<5.9)
PCB	NC (<200-<240)	NC (<23-<41)	110.0 (<39-620)	NC (<43-<59)

[A]NC = Not calculable. More than half of the samples were below the practical quantitation limit.

Table 9. Organochlorine residues (μg/kg wet weight) in sediments collected from Missouri River reservoirs in Montana during 1994. Data are presented as geometric means with ranges in parentheses.

Compound	Black Eagle (n = 2)	Rainbow (n = 2)	Cochrane (n = 2)	Ryan (n = 2)	Morony (n = 2)
p,p'-DDT	NC[A] (<2.0-<2.6)	NC (<2.5-<3.4)	NC (<2.3-<3.1)	NC (<2.9-<3.0)	NC (<3.3-<4.5)
Endosulfan Sulfate	NC (<2.0-<2.6)	NC (<2.5-<3.4)	NC (<2.3-<3.1)	NC (<2.9-<3.0)	NC (<3.3-<4.5)
Endrin Aldehyde	NC (<2.0-<2.6)	NC (<2.5-<3.4)	NC (<2.3-<3.1)	NC (<2.9-<3.0)	NC (<3.3-<4.5)
PCB	NC (<20-<26)	NC (<25-<34)	NC (<23-<31)	NC (<29-<30)	NC (<33-<45)

[A]NC = Not calculable. More than half of the samples were below the practical quantitation limit.

Table 10. Organochlorine residues ($\mu g/kg$ wet weight) in miscellaneous invertebrates and crayfish collected from the Missouri River drainage in Montana during 1995.

	Miscellaneous invertebrates		Crayfish	
Compound	Rainbow	Morony	Rainbow	Morony
alpha-BHC	<0.9	<0.5	<0.5	<0.5
beta-BHC	<0.9	<0.5	<0.5	<0.5
p,p'-DDD	<0.9	0.7	<0.5	<0.5
p,p'-DDE	1.7	1.5	1.9	1.2
p,p'-DDT	<0.9	<0.5	<0.5	<0.5
Dieldrin	<0.9	0.7	<0.5	<0.5
Endrin	<0.9	<0.5	<0.5	<0.5
Heptachlor	<0.9	<0.5	<0.5	<0.5
Total PCBs	21.9	12.0	12.5	11.2

Table 11. Organochlorine residues (µg/kg wet weight) in fish collected from the Missouri River drainage in Montana during 1994. Data are presented as geometric means with ranges in parentheses.

	Hot Springs			Holter			Great Falls			Morony	
Compound	Mountain whitefish (n = 3)	Brown trout (n = 1)	Rainbow trout (n = 2)	Rainbow trout (n = 3)	Longnose sucker (n = 3)	Brown trout (n = 1)	Rainbow trout (n = 2)	White sucker (n = 2)	Longnose sucker (n = 1)	Brown trout (n = 3)	Longnose sucker (n = 3)
alpha-BHC	NC[A] (<2.5–<2.5)	<2.5	NC (<2.5–<2.5)	NC (<1.7–<8.3)	NC (<1.7–<1.7)	<1.7	NC (<1.7–<1.7)	NC (<1.7–<1.7)	<1.7	NC (<1.7–<2.5)	NC (<2.5–<2.5)
beta-BHC	NC (<2.5–2.6)	<2.5	NC (<2.5–<2.5)	NC (<1.7–18)	NC (<1.7–<1.7)	<1.7	NC (<1.7–<1.7)	NC (<1.7–<1.7)	<1.7	NC (<1.7–<2.5)	NC (<2.5–<2.5)
p,p'-DDD	NC (<5.1–<5.1)	<5.1	NC (<5.1–<5.1)	NC (<3.3–<3.3)	NC (<3.3–<3.4)	<3.3	2.75 (<3.3–4.6)	NC (<3.3–<3.3)	<3.3	NC (<3.4–4.0)	NC (<5.1–<5.1)
p,p'-DDE	10.91 (10–13)	<5.1	4.16 (<5.1–6.8)	6.04 (<17–5.4)	11.04 (5.6–16)	5.6	8.77 (5.5–14)	NC (<3.3–<3.3)	3.7	7.49 (<3.4–19)	6.03 (<5.1–11)
p,p'-DDT	NC (<5.1–<5.1)	<5.1	NC (<5.1–<5.1)	NC (<3.3–<17)	NC (<3.3–<3.4)	<3.3	NC (<3.3–<3.3)	NC (<3.3–<3.3)	<3.3	NC (<3.4–<5.1)	NC (<5.1–7.5)
Dieldrin	NC (<5.1–<5.1)	<5.1	NC (<5.1–<5.1)	NC (<3.3–<17)	NC (<3.3–<3.4)	<3.3	NC (<3.3–<3.3)	NC (<3.3–<3.3)	<3.3	NC (<3.4–<5.1)	NC (<5.1–6.5)
Endrin	NC (<5.1–<5.1)	<5.1	NC (<5.1–<5.1)	NC (<3.3–<17)	NC (<3.3–<3.4)	<3.3	NC (<3.3–<3.3)	NC (<3.3–<3.3)	<3.3	NC (<3.4–<5.1)	NC (<5.1–6.7)
Heptachlor	NC (<2.5–<2.5)	<2.5	NC (<2.5–<2.5)	3.64 (<1.7–21)	2.46 (<1.7–6.5)	<1.7	NC (<1.7–<1.7)	NC (<1.7–<1.7)	<1.7	NC (<1.7–<2.5)	NC (<2.5–<2.5)
Total PCBs	NC (<357–<357)	<357	NC (<357–<357)	<1190	NC (<231–<238)	<231	NC (<231–<231)	NC (<231–<231)	<231	NC (<357–<357)	NC (<357–<357)

[A] NC = Not calculable. More than half of the samples were below the practical quantitation limit.

Table 12. Organochlorine residues (µg/kg wet weight) in fish collected from the Missouri River drainage in Montana during 1995. Data are presented as geometric means with ranges in parentheses.

	Hot Springs			Holter		Great Falls			Morony	
Compound	Mountain whitefish (n = 3)	Brown trout (n = 2)	Rainbow trout (n = 1)	Rainbow trout (n = 3)	Longnose sucker (n = 3)	Brown trout (n = 2)	Rainbow trout (n = 1)	Mountain whitefish (n = 3)	Brown trout (n = 3)	Longnose sucker (n = 3)
alpha-BHC	NC[A] (<0.1-6.4)	0.14 (<0.2-0.2)	0.3	0.48 (0.4-0.7)	0.58 (0.4-0.7)	NC (<0.2-<0.2)	<0.2	NC (<0.2-7.5)	0.29 (0.2-0.4)	0.90 (0.7-1.3)
beta-BHC	NC (<0.2-0.2)	NC (<0.2-<0.2)	<0.2	0.43 (<0.1-1.7)	NC (<0.2-0.3)	NC (<0.2-<0.2)	<0.2	NC (<0.2-0.2)	NC (<0.2-<0.2)	NC (<0.2-0.6)
p,p'-DDD	2.86 (2.6-3.3)	1.40 (1.3-1.5)	0.8	1.38 (1.1-1.7)	5.98 (4.6-7.5)	6.34 (5.3-9.3)	9.3	3.17 (3.1-3.2)	1.44 (0.5-3.5)	3.51 (2.6-4.5)
p,p'-DDE	19.43 (9.9-29.4)	8.50 (7.6-9.5)	3.9	7.65 (5.1-10.1)	52.06 (26.9-74.7)	24.14 (21.5-27.1)	33.3	9.60 (8.7-10.5)	8.34 (2.2-24.6)	15.61 (9.6-21.9)
p,p'-DDT	0.68 (0.7-1.1)	0.17 (<0.2-0.3)	0.4	NC (<0.2-<0.2)	0.69 (0.5-1.3)	2.77 (2.2-3.5)	5.7	1.68 (0.9-2.5)	0.27 (0.2-0.5)	2.01 (1.3-2.5)
Dieldrin	0.76 (0.7-0.9)	0.20 (0.2-0.2)	<0.2	0.51 (0.3-0.9)	0.99 (0.6-1.6)	1.62 (0.9-5.0)	5.0	1.31 (0.9-1.9)	0.82 (0.5-1.1)	1.67 (1.0-2.2)
Endrin	NC (<0.2-<0.2)	NC (<0.2-<0.2)	<0.2	NC (<0.2-<0.2)	NC (<0.2-<0.2)	NC (<0.2-<0.2)	<0.2	NC (<0.2-<0.2)	NC (<0.2-<0.2)	NC (<0.2-<0.2)
Heptachlor	NC (<0.2-0.4)	NC (<0.2-<0.2)	0.2	NC (<0.2-<0.2)	0.22 (<0.2-0.4)	NC (<0.2-<0.2)	<0.2	NC (<0.2-<0.2)	NC (<0.2-<0.2)	0.48 (0.3-0.6)
Total PCBs	46.93 (33.4-76.8)	11.90 (9.9-14.3)	8.6	19.55 (16.2-23.3)	36.35 (31.8-46.2)	99.64 (75.5-131.5)	106.5	44.34 (38.0-56.5)	34.66 (7.5-168.3)	93.43 (62.8-130.8)

[A] NC = Not calculable. More than half of the samples were below the practical quantitation limit.